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Partitioning of dietary energy of chickens fed maize- or wheat-based diets with and without a commercial blend of phytogenic feed additives

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ABSTRACT: The aim of the study was to investigate the effects of a standardized mixture of a commercial blend of phytogenic feed additives containing 5% carvacrol, 3% cinnamaldehyde, and 2% capsicum on utilization of dietary energy and performance in broiler chickens. Four experimental diets were offered to the birds from 7 to 21 d of age. These included 2 basal control diets based on either wheat or maize that contained 215 g CP/kg and 12.13 MJ/kg ME and another 2 diets using the basal control diets supplemented with the plant extracts combination at 100 mg/kg diet. Each diet was fed to 16 individually penned birds following randomization. Dietary plant extracts improved feed intake and weight gain ($P < 0.05$) and slightly ($P < 0.1$) improved feed efficiency of birds fed the maize-based diet. Supplementary plant extracts did not change dietary ME ($P > 0.05$) but improved ($P < 0.05$) dietary NE by reducing the heat increment ($P < 0.05$) per kilogram feed intake. Feeding phytogenics improved ($P < 0.05$) total carcass energy retention and the efficiency of dietary ME for carcass energy retention. The number of interactions between type of diet and supplementary phytogenic feed additive suggest that the chemical composition and the energy to protein ratio of the diet may influence the efficiency of phytogenics when fed to chickens. The experiment showed that although supplementary phytogenic additives did not affect dietary ME, they caused a significant improvement in the utilization of dietary energy for carcass energy retention but this did not always relate to growth performance.

Key words: broilers, energy metabolism, net energy, plant extracts, poultry

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INTRODUCTION

Antibiotics have been added to poultry diets to maintain health and production efficiency in the last few decades. However, to reduce the risk of developing pathogens resistant to antibiotics and also to satisfy consumer demand for a food chain free of drugs, antibiotics are being taken out of poultry diets around the world, beginning in Sweden in the year 1986 (Dibner and Richards, 2005). The withdrawal of feed antibiotics as growth promoters has increased the risk of bacterial disease, especially in growing poultry (Windisch et al., 2008). Therefore, the poultry industry needs an alternative to antibiotics as growth promoters. One such alternative is the addition of plant extracts/phytogenics/phytobiotics to poultry diets (Wallace et al., 2010). Windisch et al. (2008) defined phytogenics as plant-derived products added to the feed of healthy animals reared in common practical conditions to improve their performance, differentiating them from the plant products used for veterinary purposes.

To date, the main focus of the research on phytogenics as feed additives has been on the impact on performance variables, intestinal microflora, immune responses, and animal health (Applegate et al., 2010; Wallace et al., 2010). Less attention has been paid to the effect of supplementary phytogenics on dietary available energy. Studies on the effect of phytogenics on dietary ME did not bring conclusive information, as some authors found an increase in dietary ME in response to plant extracts (Mountzouris et al., 2010;

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Bravo et al., 2011) and others (Juin et al., 2003; Cross et al., 2007) did not. A report by Bravo et al. (2014) demonstrated that supplementary plant extracts improved dietary NE, although no significant changes in dietary ME were observed. Bird growth performance improved in accord with dietary NE, thus suggesting that studies that have focused solely on the effect of plant extracts on ME alone may well have not detected their full nutritional value (Bravo et al., 2014).

Wheat and maize are the 2 main raw materials predominantly used in poultry diets throughout the world (Panda et al., 2011). Energy and nutrient availability of wheat and maize for poultry may vary because of different chemical composition of the 2 cereals; for example, wheat has lower oil content and a greater proportion of total nonstarch polysaccharides (**NSP**) than maize (Englyst and Cumming, 1988). Although there is a paucity of information on the relative benefits of supplementation of plant extracts in different cereal-based diets, Jamroz et al. (2005) showed that the response may be different between wheat and maize. There is a need to further examine whether there is a plant extract × cereal interaction in practical diets for broiler chickens. Therefore, the objective of the present study was to compare the partitioning of energy, determined by comparative slaughter technique, resulting from feeding maize- and wheat-based diets with and without supplementary phytogenics to individually reared chickens. Individually penned birds were used to enable precise determination of the carcass energy partitioning. Dietary nutrient digestibility and energy metabolism were also determined. Growth performance variables were measured but the relatively low bird numbers were not expected to be able to detect commercially and biologically important differences.

MATERIAL AND METHODS

All procedures were approved by the Animal Experimental Committee of Harper Adams University.

Diet Formulation

Two control diets—a wheat-based diet (**W**) and a maize-based diet (**M**)—were formulated to contain 215 g CP/kg and 12.13 MJ/kg ME (Table 1). Wheat has a lower ME than maize; therefore, the W were formulated with higher added oil content to ensure that the final diets had similar ME concentrations. Higher added dietary oil content may have an impact on the digestive process (Tougas et al., 2000). However, it is the only way to increase ME content in practical poultry diet formulations. We considered that it was essential to compare diets that had the same ME contents. Both diets contained small amounts of barley and rye, but we considered that these levels would not have a major effect on digestive physiology (Annison et al., 1996). Although all the diets, including the M, contained some amounts of NSP, there is a large amount of evidence that these levels allow gut productive performance and no evidence of nonspecific diarrhea (Figueiredo et al., 2012). We considered that there was no need to add any exogenous xylanases to the experimental diets. The diets had a lower ME compared to breeder's recommendation but the energy to protein ratio was similar to the recommendations (Aviagen Ltd., Edinburgh, UK). A further 2 diets were prepared using the basal control diets supplemented

Table 1. Ingredient composition of the experimental control diets (as-fed basis)

	Content	
Item	Diet 1	Diet 2
Ingredient, g/kg		
Maize	–	528.6
Wheat	546.8	–
Soybean meal	274.9	313.0
Vegetable oil	35.0	10.0
Barley	58.4	63.3
Rye	50.0	50.0
Dicalcium phosphate	14.3	14.3
Limestone	11.5	11.5
NaCl	2.7	3.3
Lysine	1.5	1.5
Methionine	3.9	3.5
Vitamin–mineral premix[1]	1.0	1.0
Calculated analysis (as-fed basis)	1,000	1,000
ME, MJ/kg	12.12	12.13
CP, g/kg	215	215
Crude fat, g/kg	47	34
Ca, g/kg	8.4	8.3
Nonphytate P, g/kg	4.5	4.4
Lys, g/kg	12.3	12.3
Met, g/kg	6.1	6.1
Met + Cys, g/kg	9.5	9.5
Arg, g/kg	13.5	14.3
Iso, g/kg	9.8	9.4
Try, g/kg	2.4	2.6
Thr, g/kg	8.1	7.8
Val, g/kg	9.5	9.8
Analyzed values (as-fed basis)		
DM, g/kg	883	884
CP, g/kg	188.2	195.3
Crude fat, g/kg	46.2	33.2

[1]The premix provided (units/kg diet): 12,000 IU retinol, 5,000 IU cholecalciferol, 34 mg α-tocopherol, 3 mg menadione, 2 mg thiamine, 7 mg riboflavin, 5 mg pyridoxine, 15 µg cobalamin, 50 mg nicotinic acid, 15 mg pantothenic acid, 1 mg folic acid, 200 µg biotin, 80 mg Fe as iron sulfate (30%), 10 mg Cu as a copper sulfate (25%), 100 mg Mn as manganous oxide (62%), 80 mg Zn as zinc oxide (72%), 1 mg I as calcium iodate (52%), 0.2 mg Se as sodium selenite (4.5%), and 0.5 mg Mo as sodium molybdate (40%).

with a commercial blend of phytogenic feed additives (supplemental plant extracts [**XT**]; XTRACT 6930; Pancosma S.A., Geneva, Switzerland) and comprising 5% carvacrol, 3% cinnamaldehyde, and 2% capsicum oleoresin at 100 g/t, that is, **W+XT** and **M+XT**. The product was microencapsulated and thermally protected by a retention agent. The XT was added to the diets in powder form and all diets were fed as mash. The diets did not contain any coccidiostat, exogenous enzymes, antimicrobial growth promoters, prophylactics, or other similar additives.

Husbandry and Sample Collection

Eighty male Ross 308-d-old broiler chicks were obtained from a commercial hatchery and were brooded in a single floor pen and fed a standard chicken starter feed until 7 d of age. The diet did not contain any coccidiostat or antimicrobial growth promoters, prophylactics, or other similar additives. The birds were vaccinated for infectious bronchitis and Marek's disease at the hatchery.

On the first day of the experiment (7 d of age and with a mean BW [**BWm**] of 152 g), 4 birds from the general group were selected at random, killed by cervical dislocation, and stored in a freezer at –20°C for analysis. The rest of the chicks were individually weighed and sorted, and the lightest and the heaviest were discarded. Each of the 64 pens had a solid floor with an area of 0.4 by 0.4 m that was covered with clean wood shavings.

Each of the 4 experimental diets was offered to birds in each of 16 individual pens in a randomized complete block design. The room temperature was approximately 32°C at d 0 and was gradually reduced to 20°C at the end of the study. A standard lighting program for broilers was used, decreasing from 23:1 h (light:dark) from 1 d old to 18:6 h at 7 d of age, which was maintained until the end of the study.

At 18 d of age, the solid floor of each pen was replaced with a wire mesh floor, and the total excreta output was collected until the end of the study. This change did not have an effect on bird behavior and daily feed intakes (**FI**). Feed intake for the same period was recorded for the determination of dietary ME. The total trial period was 14 d, and study ended when the birds were 21 d of age. All birds were weighed at the beginning (7 d old) and at the end (21 d old) of the study, and the weight gain (**WG**) and feed conversion efficiency (**FCE**) were determined.

At the end of the study, at 21 d old, all chickens were killed by cervical dislocation and the carcass of the birds, including intestines, blood, and feathers, from each pen were frozen and then minced (TS 32 Mincing Machine; Crypto Peerless, Birmingham, UK). A comparative slaughter technique was applied to determine retention of energy (Bravo et al., 2014). The minced carcasses of the birds of each pen were thoroughly mixed and sampled. The carcass samples were freeze-dried, and carcass combustion energy content was determined and used for the following calculations. The same procedure was applied to the carcasses of 4 birds taken at the start of the experiment and the data were used to determine the carcass energy retention for the experimental period.

Chemical Analysis

The experimental diets, dried carcasses, and excreta were analyzed for combustion energy content to determine dietary ME. Combustion energy was determined using a bomb calorimeter (Parr 6200; Parr Instruments Co., Moline, IL). The N content of feed, excreta and freeze-dried carcass samples was determined using a Leco FP-528 N Analyzer (Leco Corp., St. Joseph, MI). The CP values were obtained as N × 6.25. Crude fat content in the feed, excreta and freeze-dried carcass samples was determined by the ether extraction method (method 920.39; AOAC, 1994) using a Soxtec system (Foss Ltd., Warrington, UK).

Calculations

Dietary ME (MJ/kg DM) was calculated as follows:

$$ME = (E\_int - E\_out)/FI,$$

in which E_int is the GE (MJ/kg) intake of the birds during the final 3 d of the study between 18 and 21 d of age, E_out is the energy (MJ/kg) output of the birds during the final 3 d of the study between 18 and 21 d of age, and FI (kg/DM) of the birds is measured during the same period.

The total energy retained in the carcass (**REc**; MJ) was calculated as follows:

$$REc = (E_{21} - E_7),$$

in which E_{21} is the total energy (MJ) of chicken carcass at 21 d old and E_7 is the total energy (MJ) of chicken carcass at the beginning of the experiment at 7 d old.

The total carcass protein retention (**CPr**; g/bird) was calculated as follows:

$$CPr = (N_{21} - N_7) \times 6.25,$$

in which N_{21} is the N (g) in chicken carcasses at 21 d old, N_7 is the N (g) in chicken carcasses at the begin-

ning of the experiment at 7 d old, and 6.25 is the coefficient used to calculate the protein retained in the body.

The value of the carcass GE retained as protein (**REp**) was calculated as

$$REp = CPr \times 23.6 \text{ MJ},$$

in which CPr (kg) is multiplied by 23.6 MJ, the amount of energy in 1 kg of protein according to Okumura and Mori (1979).

It was assumed that the difference between REc and REp yields the value for the GE retained as body fat (**REf**). The amount of retained carcass fat was calculated as the REf divided by the value of 39.12 MJ/kg (Okumura and Mori, 1979).

The fasting heat production (**FHP**; MJ/bird) was estimated to be 0.450 MJ/d per kg of metabolic BW (**MBW**, calculated as $\mathbf{BW^{0.70}}$) per day, which corresponds to the asymptotic heat production at zero activity, as proposed by Noblet et al. (2010). The BWm was assumed to be the start weight of the bird + (WG/2). The mean $BW^{0.70}$ was calculated as $BWm^{0.70}$.

Dietary NE (MJ/kg DM) was calculated using the following equation:

$$NE = (REc + FHP)/FI,$$

in which FI is the DM (kg) consumed from d 7 to 21.

The efficiency of ME used for energy retention (efficiency of dietary apparent ME retention [**Kre**]) was calculated as the REc divided by the ME intake:

$$Kre = REc/ME \text{ intake}$$

in which ME intake was the FI (kg DM) from 7 to 21 d old multiplied by determined ME (MJ/kg DM) of the diets.

Heat Production

Heat increment (**HI**) is the heat produced by a bird in excess of that associated with fasting (or basal) metabolism, that is, FHP. The HI per kilogram FI (HIfi; MJ/kg DM) of the birds from 7 to 21 d old (HPf) was calculated as

$$HIfi = (ME \text{ intake} + FHP - REc)/FI,$$

in which the difference between ME intake and REc is the total HI per bird (MJ), which consists of the energy for digesting the food, tissue retention, and the cost of anabolism, and FI is the DM (kg) consumed from d 7 to 21. Although ME was determined only for the last 3 d of the study, we assumed that there were no significant changes in dietary ME during the entire study period.

The NE:ME ratio was used as criteria for the conversion of dietary ME to NE. A lower ratio indicates that less ME was used as NE and relatively more heat was released as HI, instead of being used for carcass energy retention and maintenance.

The total tract DM retention coefficient (**DMR**), total tract N retention coefficient (**NR**), and total tract fat retention coefficient (**FD**) were calculated for the last 3 d of the study following standard procedures.

Statistical Analyses

Data were statistically analyzed with a randomized block ANOVA using a 2 × 2 factorial arrangement of treatments. The blocking factor was the position of the pens within the experimental room. The treatments factors were the cereals (maize and wheat) and the XT (with and without) used. Statistical analyses were performed by GenStat (GenStat, 15th edition; Lawes Agricultural Trust, VSN International Ltd., Oxford, UK). The ME intake was used as a covariate in the analysis of energy utilization response data, because of the possible influence of variation in ME intake on the energy utilization response criteria. Regression analysis was used to assess the relationship between variables of broiler growth performance and determined available energy values. In all instances, differences were reported as significant at $P < 0.05$ and trends were noted when the *P*-value was less than 0.1.

RESULTS

The analyzed chemical composition of the 2 basal diets is shown in Table 1. The protein content was higher although the content of dietary fat was lower in the M when compared to the W. The M had relatively low GE compared to the W: 16.28 vs. 16.69 MJ GE/kg diet, respectively. The diets had the same DM content.

All birds remained healthy throughout the study period and there was no mortality. Table 2 shows the data on growth performance of the chickens, dietary ME, and daily ME intake. There were cereals × XT interactions ($P < 0.05$) regarding WG and MWG and a nonsignificant trend for interactions regarding FI ($P = 0.061$) and FCE ($P = 0.069$) of the birds. Broilers fed the M+XT diet had 9.1, 13.5, and 5.2% greater daily FI ($P = 0.061$), WG ($P < 0.05$), and FCE ($P = 0.069$), respectively, although there was no response to XT from the birds fed W+XT diets ($P > 0.05$). Dietary ME was not influenced ($P > 0.05$) by the cereal type or XT inclusion. However, birds fed the M+XT diet had 9.4% greater ($P < 0.05$) daily ME intake, but no response was observed from the birds fed W+XT diets ($P > 0.05$).

Similar to growth performances and ME intake, birds fed the M+XT diet retained 9.9% more ($P < 0.05$)

Table 2. Effect of the experimental diets on broiler chickens[1]

	Treatment factor[3]											
Item[2]	FI, g DM/bird	WG, g/bird	CPr, g/bird	CFr, g/bird	FCE, DM	MBW, kg	DMR	NR	FD	ME, MJ/kg DM	ME intake, MJ bird	ME intake, MJ/kg MBW
Diet												
W	663	491	83.4	56.2	0.741	523	0.764	0.674	0.826	14.17	9.41	17.95
M	672	517	90.9	47.9	0.766	537	0.772	0.694	0.777	14.03	9.42	17.54
XT												
–	655	488	86.4	48.2	0.743	522	0.769	0.689	0.805	14.12	9.25	17.69
+	681	520	87.9	55.9	0.764	537	0.768	0.679	0.797	14.10	9.58	17.80
SEM	14.3	12.5	2.32	2.34	0.0081	6.5	0.0036	0.0048	0.0093	0.072	0.180	0.178
Diet and XT												
W–	670	496	86.7	53.7	0.741	527	0.760	0.674	0.826	14.15	9.51	18.02
W +	657	485	80.1	58.7	0.740	519	0.769	0.673	0.826	14.20	9.31	17.89
M–	640	479	86.2	42.7	0.746	518	0.777	0.703	0.785	14.09	9.00	17.36
M +	704	554	95.7	53.0	0.787	556	0.767	0.685	0.769	13.99	9.85	17.71
SEM	20.2	17.7	3.28	3.31	0.0114	9.2	0.0051	0.0067	0.0131	0.102	0.254	0.251
Probabilities of statistical differences												
Diet	0.670	0.147	0.025	0.015	0.028	0.134	0.165	0.004	< 0.001	0.209	0.952	0.102
XT	0.204	0.073	0.653	0.025	0.080	0.107	0.860	0.176	0.538	0.813	0.208	0.672
Diet and XT	0.061	0.018	0.018	0.425	0.069	0.017	0.078	0.224	0.561	0.464	0.045	0.346
CV, %	12.1	14.0	15.0	25.5	6.0	7.0	2.7	3.9	6.5	2.9	10.8	5.7

[1]Based on feeding period from 7 to 21 d of age for growth performance and ME intake and from 17 to 21 d of age for total tract DM retention coefficient, total tract N retention coefficient, total tract fat retention coefficient, and ME and 16 observations per treatment.

[2]W = wheat-based diet; M = maize-based diet; XT = supplemental plant extracts (100 g XT/t; XTRACT 6930; Pancosma S.A., Geneva, Switzerland); (–) = diet was not supplemented with XT; (+) = diet was supplemented with XT.

[3]FI = feed intake; WG = weight gain; CPr = carcass protein retention; CFr = carcass fat retention; FCE = feed conversion efficiency; MBW = mean metabolic BW; DMR = total tract DM retention coefficient; NR = total tract N retention coefficient; FD = total tract fat retention coefficient.

carcass protein, but no response was observed from the birds fed the W+XT diet ($P > 0.05$). Birds fed W retained 14.8% more carcass fat than birds fed M diets. Feeding XT improved overall carcass fat retention by 13.8% compared to control diets.

Maize-based diets had higher ($P = 0.004$) NR and lower FD ($P < 0.001$) coefficients compared to wheat. The DMR, NR, and FD did not differ ($P > 0.05$) due to treatment.

There were no differences ($P > 0.05$) in the ME intake per kilogram of $BW^{0.70}$, indicating that the variation in FI were explained by the metabolic requirements of the birds.

Table 3 describes heat production of broiler chickens. There was an XT × diet type interaction for total heat production (**HP**) and FHP data. Dietary plant extracts supplementation reduced ($P < 0.05$) HP of W without changing those of M. Birds fed XT-supplemented M had an increased FHP ($P < 0.05$), but no change was observed for wheat-fed birds. The total HI (**HIt**) was not affected ($P > 0.05$) by dietary type or XT supplementation. However, birds fed XT had reduced HI for a kilogram DM intake (**HIf**) by 14.2% ($P < 0.05$) and HP:ME intake ratio by 5.5% ($P < 0.05$). The HI:HP ratio tended ($P = 0.102$) to be reduced by dietary XT supplementation.

Table 4 shows the data on the variables describing the energy metabolism of the experimental birds. Birds fed XT retained about 7.7% more REc and 13.7% more REf than birds fed controls ($P < 0.05$). However, birds fed the M+XT diet retained 10.2% more ($P < 0.05$) REp compared to control ($P < 0.05$), but no response was observed from the birds fed the W+XT diet ($P > 0.05$). Feeding XT enhanced Kre, dietary NE, and NE:ME ratio by 7.6 ($P < 0.05$), 3.6 ($P < 0.05$), and 3.6% ($P = 0.057$), respectively. Wheat-based diets tended ($P < 0.1$) to have higher Kre and NE compared to M. As expected, the CV was higher for NE compared to ME: 6.9 vs. 2.9%, respectively.

DISCUSSION

The experimental M and W were formulated to be isoenergetic and isonitrogenic to allow testing of the responses to supplementary mixture of plant extracts on studied parameters. However, the differences in the analyzed protein and fat contents between the 2 basal diets may be due to differences between the composition of the ingredients that were used in the present study and their book values.

The results obtained in the present study confirmed the stimulating growth effect of the mixture of phyto-

Table 3. Heat production of broiler chickens[1]

	Treatment factor[3]					
Item[2]	HP, MJ	FHP, MJ	HIt, MJ	HIf, MJ/kg DM	HP:ME int	HI:HP
Diet						
W	5.21	3.29	1.92	2.86	0.554	0.361
M	5.41	3.38	2.02	3.05	0.576	0.366
XT						
–	5.35	3.29	2.06	3.18	0.581	0.377
+	5.26	3.39	1.87	2.73	0.549	0.350
SEM	0.106	0.041	0.097	0.151	0.0093	0.0114
Diet and XT						
W–	5.41	3.32	2.09	3.12	0.570	0.383
W+	5.01	3.27	1.74	2.60	0.537	0.339
M–	5.30	3.26	2.03	3.24	0.592	0.371
M+	5.51	3.50	2.01	2.86	0.560	0.361
SEM	0.150	0.058	0.137	0.213	0.0131	0.0162
Probabilities of statistical differences						
Diet	0.194	0.134	0.433	0.374	0.092	0.773
XT	0.531	0.107	0.174	0.039	0.017	0.102
Diet × XT	0.042	0.017	0.225	0.742	0.957	0.291
CV, %	11.3	7.0	27.9	28.8	9.3	17.8

[1]Based on feeding period from 7 to 21 d of age and 16 observations per treatment.

[2]W = wheat-based diet; M = maize-based diet; XT = supplemental plant extracts (100 g XT/t; XTRACT 6930; Pancosma S.A., Geneva, Switzerland); (–) = diet was not supplemented with XT; (+) = diet was supplemented with XT.

[3]HP = total heat production; FHP = fasting heat production; HIt = total heat increment; HIf = heat increment for a kilogram DM intake; HP:ME int = ratio between HP and ME intake: HI = heat increment.

Table 4. Energy metabolism of broiler chickens[1]

	Treatment factor[3]					
Item[2]	REc, MJ	REf, MJ	REp, MJ	Kre	NE, MJ/kg DM	NE/ME
Diet						
W	4.17	2.20	1.97	0.446	11.35	0.800
M	4.02	1.87	2.15	0.424	10.99	0.784
XT						
–	3.93	1.89	2.04	0.419	10.97	0.778
+	4.26	2.19	2.07	0.451	11.37	0.806
SEM	0.140	0.092	0.055	0.0093	0.137	0.0101
Diet and XT						
W–	4.15	2.10	2.05	0.430	11.09	0.784
W+	4.19	2.30	1.89	0.463	11.60	0.816
M–	3.71	1.67	2.03	0.408	10.85	0.772
M+	4.33	2.08	2.26	0.440	11.13	0.796
SEM	0.197	0.130	0.077	0.0131	0.194	0.0143
Probabilities of statistical differences						
Diet	0.460	0.015	0.025	0.092	0.072	0.256
XT	0.096	0.025	0.653	0.017	0.048	0.057
Diet × XT	0.143	0.425	0.018	0.957	0.568	0.775
CV, %	19.3	25.5	15.0	12.0	6.9	7.2

[1]Based on feeding period from 7 to 21 d of age and 16 observations per treatment.

[2]W = wheat-based diet; M = maize-based diet; XT = supplemental plant extracts (100 g XT/t; XTRACT 6930; Pancosma S.A., Geneva, Switzerland); (–) = diet was not supplemented with XT; (+) = diet was supplemented with XT.

[3]REc = total energy retained in the carcass; REf = GE retained as body fat; REp = carcass GE retained as protein; Kre = efficiency of dietary apparent ME retention; NE/ME = conversion coefficient of dietary ME to NE.

genics including carvacrol, cinnamaldehyde, and capsicum oleoresin, which was previously observed (Jamroz et al., 2003; Bravo et al., 2011, 2014). In agreement with Jamroz et al. (2005), better growth performance and feed efficiency were noted when the same product was added to a M but not to wheat. Compared to maize, wheat contains more water-soluble NSP, a carbohydrate complex possessing antinutrient activity, which may reduce dietary nutrient availability (Annison et al., 1996), thus explaining the improved growth performance of birds fed maize and supplemented with XT.

Further partitioning of the chicken carcass into composition of gain showed that protein was responsible for the larger share of carcass than fat. This is in agreement with previous reports studying carcass composition of ad libitum fed birds at a similar age (Pirgozliev and Bedford, 2013; Bravo et al., 2014).

An improvement in growth performance and protein retention of maize- but not wheat-fed birds with XT supplementation was coupled with an increase in dietary ME intake, although no changes in dietary ME per se were observed. The ME response to supplementary XT varies between different reports (Bravo et al., 2011, 2014). The efficiency of energy utilization from dietary carbohydrates, fats, and protein was 0.7, 0.9, and 0.6, respectively (DeGroote, 1974). The ME response to XT may also depend on the concentration and digestibility of the main dietary nutrients. This suggests that supplementary XT may influence dietary ME intake and bird growth via a combination of improved energy metabolizability and FI, and the importance of each may depend on dietary composition. Indeed, at early stages of growth, broilers deposit proportionally more carcass protein than fat (Leeson and Summers, 1997), so an increase in daily FI may well lead to increased carcass protein retention. In addition, the energy to protein ratio in the XT-supplemented maize diet was narrower (the same ME but higher CP) compared to the XT-supplemented wheat diet, which may also have contributed to the increased protein deposition in maize-fed birds (Macleod, 1990). This could also be a result of better AA digestibility in the M evoked by the plant extracts mixture (Jamroz et al., 2005). Although there were no differences in the determined ME concentration of any of the diets, the M had lower added oil content and lower carcass fat retention compared to the W. However, there was no interaction with dietary

XT. The W had a higher level of added fat compared to the maize (35 vs. 10 g/kg, respectively), although there was a smaller difference in the total fat contents (46.2 vs. 33.2 g/kg, respectively). It is possible these differences in the fat content may have affected the digestive process, particularly gastric emptying (Tougas et al., 2000).

Similar to a previous study (Bravo et al., 2014), dietary NE of XT-supplemented diets improved with 0.40 MJ/kg DM. The improvement in dietary NE was coupled with a 0.45-MJ reduction in HIf, suggesting that the beneficial effects of supplementary XT to poultry diets seems to be mediated through relative decrease in the energy required for anabolism, thereby allowing birds to divert more energy toward carcass retention or growth rather than heat loss. Feeding phytogenic feed additives including carvacrol and capsicum oleoresin improved gut health in weaned pigs, reducing gut microbial proliferation and consequent inflammation, and increasing ileal villi maintaining normal intestinal integrity and function (Michiels et al., 2010; Liu et al., 2013). Intensified microbial proliferation in the gastrointestinal tract will result in increased energy requirement for maintenance, that is, heat production, and an impaired efficiency of nutrient utilization (Dibner and Richards, 2005). There is published evidence of the protective effect of low feed inclusion of these plant extracts alone or in combination on against pathogens (Lillehoj et al., 2011; Lee et al., 2011, 2013). Also, the same commercial blend of phytogenic feed additives (XT) enhanced antioxidant status of birds (Karadas et al., 2013, 2014) that could also explain a better protection and less energy required for maintenance.

Total heat production constituted 56% of the ME intake, and HIt constituted 36% of the HP, which is similar to values reported by van Milgen et al. (2001).

Birds fed XT retained more carcass energy by utilizing dietary ME more efficiently. This is further supported by the improved utilization of dietary ME as NE when XT was supplemented to diets. The NE:ME ratios were similar to previous reports (Swick et al., 2013).

Addition of dietary XT gave an increase of carcass fat retention in both wheat and maize diets but an increase in carcass protein retention only in the maize diet. Although the wheat and maize diets were formulated to be isoenergetic and isonitrogenic, the analytical data shows that the wheat diet was 3.6% lower in protein. The additional energy available to birds due to XT supplementation may have allowed increases in both carcass protein and fat deposition in the maize diet but only fat deposition in W. Boekholt et al. (1994) showed that when protein is not limiting in the diets of broilers, extra energy value in the diet is used for both protein and fat retention.

The number of dietary type × XT interactions observed in bird growth performance, heat production, and energy metabolism in this study may be due to the relatively high fat content of the W compared to M and not to the cereals alone. However, the impact of dietary formulation (cereals, protein sources, fat content, etc.) on the effectiveness of supplementary plant extracts in poultry nutrition warrants further investigation.

Bravo et al. (2014) concluded that studies that have focused solely on the effect of phytogenics on ME alone may not be sensitive enough to detect their full nutritional value, suggesting that dietary NE is the better way to evaluate broiler response to phytogenics supplementation. Dietary NE is the ME of the diet corrected for the energy losses that result from the heat released during absorption of the dietary nutrients and accretion of body mass. Although changes in maintenance energy, for example, heat production, are more likely to be detected by determination of NE compared to ME (Pirgozliev and Bedford, 2013; Bravo et al., 2014), changes in growth performances may not always relate to dietary available energy. Muscle and fat are the 2 main components of the bird growth studied. Birds fed W and also XT retained more carcass fat compared to the rest of the birds, which was coupled with an increase in NE. Fat and protein contain different amounts of GE but require the same energy to be deposited in the body, resulting in more efficient fat deposition and low HP (Macleod, 1990). Indeed, birds fed XT-supplemented W (containing more fat) had reduced HP compared to those fed maize diets. Widening the dietary ME to protein ratio is likely to affect more abdominal fat retention than bird growth performances (Niu et al., 2009), suggesting an explanation for the inconsistency between growth performance and NE of birds fed W.

In summary, the present results support previous findings (Bravo et al., 2014) that a dietary combination of a commercial blend of phytogenic additives improved dietary NE of poultry diets. The experiment showed that although supplementary phytogenic additives did not affect dietary ME, they caused a significant improvement in the utilization of energy for carcass energy retention.

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